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(54) Cryogenic air separation

Tieftemperaturzerlegung von Luft

Séparation cryogénique d'air

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(73) Proprietor: **THE BOC GROUP, INC.**
Murray Hill, New Jersey 07974 (US)

(72) Inventor: **Mostello, Robert A.**
Somerville, New Jersey 08876 (US)

(74) Representative: **Wickham, Michael et al**
c/o Patent and Trademark Department
The BOC Group plc
Chertsey Road
Windlesham Surrey GU20 6HJ (GB)

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Description

This invention relates to air separation.

Components of gaseous mixtures having different volatilities are separated from one another by a variety of well-known cryogenic rectification processes. Such processes utilize a main heat exchanger to cool the gaseous mixture to a temperature suitable for rectification after the gaseous mixture has been compressed. The rectification is carried out in distillation columns incorporating trays or packing (structured or random) to bring liquid and gaseous phases of the mixture into intimate contact and thereby separate the components of the mixture in accordance with their volatilities. In order to avoid the use of a product compressor to produce the lower volatility component at a delivery pressure, the distillation is carried out such that the lower volatility component is produced in liquid form. The lower volatility component in the liquid form is then pumped to the delivery pressure and vaporized within the main heat exchanger.

An important cryogenic rectification process concerns the separation of air. Air contains a lower volatility component, oxygen, and a higher volatility component, nitrogen. In the production of pressurized oxygen gas, a liquid oxygen product of the cryogenic rectification of air is pumped to a delivery pressure and heated by incoming air in a heat exchanger from which it emerges as a pressurized gas. Typically, at least part of the air feed must be pressurized to a much higher pressure than the oxygen in order to provide the appropriate temperature difference in the heat exchanger. For instance, when an oxygen product, which amounts to about 21% of the incoming air by volume is pumped to 42.8 bar(a), about 35-40% of the incoming air is compressed to about 74.5 bar(a). This requirement is a result of the non-conformity in the temperature and the heat transferred between the feed air and the product streams in some parts of the main heat exchanger, which affects the warming of the products and the cooling of the air. Concurrently, wide temperature differences exist between the air and the product streams in part of the heat exchanger. This is known as thermodynamic irreversibility and increases the energy requirement of the process.

EP-A-0-504029 and EP-A-0-505 812 both relate to processes in which liquid oxygen is pumped from a rectification column through a main heat exchanger in countercurrent heat exchange with air and is thereby vaporized. In both cases all compression of air is performed upstream of the main heat exchanger.

All the features set out in the pre-characterising part of Claim 1 hereinbelow are disclosed in EP-A-0 505 812.

As will be discussed, the present invention provides a process and apparatus for the separation of air in which thermodynamic irreversibilities in the main heat exchanger are minimized.

According to the present invention there is provided a process for separating air including the steps of forming a first lower pressure stream and a second higher pressure stream of compressed air;

cooling the first air stream by heat exchange in a main heat exchanger to a temperature suitable for its separation by rectification;

rectifying the first air stream to form nitrogen and liquid oxygen fractions;

pressurising a stream of the liquid oxygen fraction;

heat exchanging a stream of the nitrogen fraction and the pressurised liquid oxygen stream with the first air stream so as to effect the cooling of the first air stream and vaporisation of the pressurised liquid oxygen stream;

cooling the second air stream by heat exchange in the main heat exchanger with the nitrogen and pressurised liquid oxygen streams to a temperature intermediate the cold end and warm end temperatures of the main heat exchanger, characterised by introducing at least part of the cooled second air stream at said intermediate temperature into a compressor ;

compressing said part of the cooled second air stream in the compressor ; and further cooling the compressed part of the cooled second air stream in the main heat exchanger and rectifying the further cooled second air stream with the first air stream, and in that the said intermediate temperature to which the second air stream is cooled is in the vicinity of a theoretical pinch point temperature determined for the main heat exchanger.

The invention also provides an apparatus for producing an oxygen product at a delivery pressure from air, said apparatus comprising:

a main compressor for compressing the air;

a first after-cooler communicating with the main compressor for removing heat of compression from the air;

air pre-purification means communicating with the first after-cooler for purifying the air; a high pressure air compressor connected to the air pre-purification means for further compressing at least a portion of the air to form a further compressed air stream;

a second after-cooler communicating with the high pressure air compressor for removing heat of compression from the further compressed air stream;

a main heat exchanger having a first passageway including first and second sections, the first section in communication with said second after-cooler such that said compressed air stream flows into said first section of the first passageway, a second passageway, means for discharging first and second subsidiary air streams composed of the compressed air stream from the first section of the first passageway so that at least the first subsidiary air stream upon discharge has a temperature in the vicinity of a theoretical pinch point temperature determined for the main heat exchanger, and an inlet situated at a location of the main heat exchanger having a warmer temperature than the theoretical pinch point temperature for receiving the first subsidiary air stream after compression thereof, the second section of the first passageway communicating with the inlet and positioned such that the first subsidiary air stream fully cools;

a heat pump compressor for compressing the first subsidiary air stream intermediate the said discharge means of the main heat exchanger and the said inlet thereto; expansion means for expanding the second subsidiary air stream with the performance of expansion work;

the expansion means coupled to the heat pump compressor such that at least part of the expansion work drives the heat pump compressor;

air rectification means connected to the expansion means and the second section of the first passageway of the main heat exchanger for rectifying the air and thereby producing liquid oxygen;

a pump connected to the air rectification means for pumping the liquid oxygen and thereby forming a pumped liquid oxygen stream;

the pump connected to the second passageway of the main heat exchanger such that the pumped liquid oxygen stream flows in a counter-current direction to the compressed air stream within the first passageway and is thereby vaporized to produce the gaseous oxygen product; and

refrigeration means for supplying refrigeration to the apparatus such that energy balance thereof is maintained.

As is known in the art, there typically tends to be created in operation of a heat exchanger a pinch point. The pinch point temperature is a temperature within the main heat exchanger where there exists a minimum difference in temperature between all the streams to be cooled in the main heat exchanger versus all the streams to be warmed in the main heat exchanger. Above and below this pinch point temperature, temperature differences and enthalpies diverge. The divergence is a measure of the thermodynamic irreversibility present within the main heat exchanger. This thermodynamic irreversibility represents lost work and therefore part of the energy requirements of the plant that are necessary in vaporizing the product oxygen stream. The term "theoretical pinch point temperature" as used herein and in the claims means the pinch point temperature determined for the collective cold streams in the main heat exchanger by for instance, simulation, that would exist if the first and second subsidiary air streams were never formed. In such case, the main heat exchanger would be operating in the manner of a known heat exchanger in which all of the further compressed air stream is fully cooled within the main heat exchanger. In the known main heat exchanger, if the heating and cooling curves were plotted as temperature versus enthalpy, the pinch point temperature and divergence of these curves would be readily apparent. As will be further discussed, when the cooling and heating curves of a main heat exchanger operated in accordance with the present invention are compared with the known case, it can be seen that there is less divergence between the curves and therefore less lost work involved in vaporizing the pumped liquid oxygen stream. More specifically, the use of the first subsidiary air stream reduces thermodynamic irreversibility between the theoretical pinch point temperature (which is typically substantially the same as the actual pinch point temperature) and the temperature at which the first subsidiary air stream is reintroduced into the main heat exchanger. In addition, the withdrawal of the second subsidiary air stream for cooling by work expansion rather than in the main heat exchanger lowers thermodynamic irreversibility below the theoretical and actual pinch point temperature. The first subsidiary air stream is generally taken from a first location and returned to a second location in the main heat exchanger selected so as to obtain a relatively close match between the temperature-enthalpy curve of the streams being warmed

and that of the streams being cooled.

It should also be noted that the term "main heat exchanger" as used herein and in the claims is not necessarily limited to a single, (plate fin) heat exchanger. A "main heat exchanger," as would be known to those skilled in the art, could be made up of several units working in parallel and/or in series to cool and warm streams. (The use of high and low pressure heat exchangers is conventional in the art.) Collectively the units making up the "main heat exchanger" would have a theoretical pinch point temperature. The terms "fully cooled" and "fully warmed" as used herein mean cooled to rectification temperature and warmed to ambient, respectively. The term "partially" in the context of "partially warmed" or "partially cooled", as used herein means warmed or cooled to a temperature between fully warmed and fully cooled temperatures. Lastly, the term "vicinity" as used herein with reference to a theoretical pinch point temperature means a temperature within a range of between plus or minus 50° C from the theoretical pinch point temperature.

In an apparatus for performing the preferred embodiment of the process according to the invention, there is a main compressor for compressing the air. A first after-cooler communicates with the main compressor for removing heat of compression from the air and an air purification means communicates with the first after-cooler for purifying the air. A high pressure air compressor communicates with the air purification means for further compressing at least a portion of the air to form a further compressed air stream. A second after-cooler for removing the heat of compression from the compressed air stream communicates with the high pressure air compressor. A main heat exchanger is provided. The main heat exchanger has first and second passageways. The first passageway includes first and second sections and the first section thereof is in communication with the second after-cooler such that the compressed air stream flows into the first section of the first passageway. A means is provided for discharging first and second subsidiary air streams composed of the compressed air stream from the first section of the passageway so that at least the first subsidiary stream upon discharge has a temperature in the vicinity of a theoretical pinch point temperature. An inlet is provided at a location of the main heat exchanger having a higher temperature than the theoretical pinch point temperature for receiving the first subsidiary air stream after the compression thereof. The second section of the first passageway is in communication with the inlet and position such that the first subsidiary air stream is fully cooled within the main heat exchanger. A heat pump compressor has an inlet communicating with the discharge means of the main heat exchanger and an outlet communicating with the inlet for the compressed first subsidiary air stream. An expansion means is provided for expanding the second subsidiary air stream with the performance of external work. The expansion means is coupled to the heat pump compressor such that at least part of the work is used to drive the heat pump compressor. An air rectification means communicates with the expansion means and the second section of the first passageway of the main heat exchanger for rectifying the air and thereby producing liquid oxygen. A pump communicates with the air rectification means and is operable to raise the liquid oxygen to the delivery pressure. The pump communicates with the second passageway of the main heat exchanger such that the pumped liquid oxygen stream flows in a countercurrent direction to the compressed air stream and is thereby vaporized to produce the gaseous oxygen product. A refrigeration means is provided for supplying refrigeration to the apparatus such that energy balance thereof is maintained.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic of an air separation plant in accordance with the process and apparatus of the present invention;

Figure 2 is a graph of temperature versus enthalpy of a heat exchanger of the prior art; and

Figure 3 is a graph of temperature versus enthalpy of a heat exchanger constructed and operated in accordance with the present invention.

With reference to Figure 1 of the drawings, an air separation plant 10 for carrying out a method in accordance with the present invention is illustrated.

A stream of air to be rectified is compressed in a main compressor 12 to form a compressed air stream 13. The heat of compression is removed from the compressed air stream 13 by a first after-cooler 14, typically water-cooled, and the compressed air stream 13 is purified by an air pre-purification unit 16 in which carbon dioxide, moisture and hydrocarbons are removed by adsorption from the air. A high pressure compressor 18 communicates with the air pre-purification unit 16 and operates to form a further compressed air stream 20. After passage through a second after-cooler 22 (to remove heat of compression from the further compressed air stream) the further compressed air stream 20 is introduced into a main heat exchanger 24. The main heat exchanger 24 has a first passageway 26 having first and second sections 26a and 26b in communication with a second after-cooler 22. The further compressed air stream 20 flows into first passageway 26. A second passageway 28 is provided for vaporizing a pumped liquid oxygen stream that will be discussed hereinafter. The first section 26a of first passageway 26 is provided with outlets for discharging first and second subsidiary air streams 30 and 32 from the main heat exchanger 24. The first subsidiary air stream 30

is yet further compressed within a heat pump compressor 34. A resulting compressed air stream 36 is introduced into the second section 26b of the first passageway 26 of the main heat exchanger 24 through an inlet communicating with a location in the heat exchanger 24 at a higher temperature than the theoretical or actual pinch point temperature. At the same time, the second subsidiary air stream 32 is introduced into a turboexpander 38 that expands second subsidiary air stream 32 sufficiently that it is cooled to a temperature suitable for its rectification. The turboexpander 38 may be coupled to the heat pump compressor 34 mechanically. Alternatively, the compressor 34 may be driven by an electric motor (not shown). The necessary electrical power for operating the motor may be generated by the turboexpander 38 if the latter is coupled to an electrical generator. Excess energy, above that required to drive heat pump compressor 34, may be produced by turboexpander 38. In such case the excess energy could be applied elsewhere in the plant. For instance, excess electricity generated by the generator coupled to turboexpander 38 could be used for other electrical needs in the plant.

It is by removal of the first and second subsidiary air streams and their utilization as described above within compressor 34 and turboexpander 38 coupled to one another, that the thermal irreversibilities of the main heat exchanger 24 above and below the theoretical pinch point temperature (and the actual pinch point temperature) are minimized. A more detailed discussion of this will be set forth hereinbelow.

Although an air separation plant can operate as thus far described, preferably not all of the air is compressed within high pressure air compressor 18 but rather, downstream of air pre-purification unit 16, the compressed air stream 13 is divided into first and second partial streams 40 and 42. The first partial stream 40 is subjected to further compression within high pressure air compressor 18. The second partial stream 42 is divided into third and fourth subsidiary air streams 44 and 46. The third subsidiary air stream 44 is fully cooled within a third passageway 48 of the main heat exchanger 24 provided for such purpose. The fourth subsidiary air stream 46 is further compressed within a refrigeration booster-compressor 50 and the heat of compression is removed by an after-cooler 52. With its heat of compression removed, the fourth subsidiary air stream 46 is partially cooled within a fourth passageway 54 of the main heat exchanger 24 provided for such purpose. The fourth subsidiary air stream 46 is withdrawn from main heat exchanger 24 and is passed through a refrigeration turboexpander 56 coupled to refrigeration booster compressor 50. The exhaust of refrigeration turboexpander 56 is returned through a fifth passageway 58 of the main heat exchanger 24. The main heat exchanger 24 is also provided with a sixth passageway 60 for fully warming a waste nitrogen stream (that will be discussed in more detail hereinafter) to ambient temperature and for use in regenerating pre-purification unit 16.

With reference to Figure 2 of the accompanying drawings, the temperature and enthalpy characteristics of a known heat exchanger are plotted. The heat exchanger used in deriving such plot is similar to the heat exchanger described above except that all of the further compressed stream is fully cooled to a rectification temperature within the main heat exchanger and none of it is removed to form first and second subsidiary air streams 30 and 32. Curve A is the sum of all of the streams to be cooled in the main heat exchanger. Curve B represents the sum of the enthalpy and temperatures at discrete points within the main heat exchanger of the streams to be warmed. In order for there to be heat transfer between the streams being cooled and those being warmed, there must be a temperature difference between the streams at any point in the main heat exchanger. The streams undergoing cooling must have a higher temperature than the streams being warmed. A point is reached though, where there is a minimum temperature difference, namely a pinch point temperature C. The distance between the curves, for instance distance D above the pinch point temperature and distance E below the pinch point temperature are indicative of the thermodynamic irreversibilities inherent within such a main heat exchanger. This thermodynamic irreversibility represents lost work, which translates into extra work of compression.

With reference to Figure 3 of the accompanying drawings, the temperature-enthalpy characteristics of main heat exchanger 24 are plotted. It is to be noted that the pinch point temperature of the heat exchanger of Figure 2 is the theoretical pinch point temperature of heat exchanger 24 for reasons discussed above. It is immediately apparent that the curves coincide more closely than in Figure 2. It is to be noted that the pinch point temperature differences are the same (1.6°C) in both cases. Curve A' is the composite of all the streams to be cooled, including for instance, further compressed air stream 20 passing through passageway 26, and third subsidiary air stream 44 passing through passageway 48. Curve B' is the sum of the temperature enthalpy characteristics at any point within the main heat exchanger of all the streams to be warmed, namely oxygen stream 94 passing through passage 28 and the waste nitrogen stream 92 passing though passageway 60. In the main heat exchanger 24 (at the same points considered for the known main heat exchanger whose operation is represented in Figure 2) the temperature difference between the curves at point D', (which is at a temperature higher than the actual pinch point temperature C' or the theoretical pinch point temperature C), and the temperature difference at point E' (which is at a temperature lower than the actual pinch point temperature C' or the theoretical pinch point temperature C) are much less than in the known heat exchanger. As a result, less energy is supplied to high pressure compressor 18 than an equivalent compressor needed for use with the known heat exchanger to accomplish the same rate of vaporization of the pumped oxygen stream to be extracted from main heat exchanger 24 as a product. Maintaining close temperature differences is more important as the temperature of heat transfer decreases.

Returning to Figure 1, downstream of the cooling of the air streams in the main heat exchanger 24, they are rectified in a double rectification column 62 comprising a high pressure column 64 and a low pressure column 66 operatively associated in a heat transfer relationship with one another by a condenser-reboiler 68. The air that has been is cooled to a temperature suitable for its rectification, namely at or near its dew point, is introduced into the high pressure column 64 so that an oxygen-rich liquid fraction forms at the bottom thereof and a nitrogen-rich fraction forms at the top of the column. The nitrogen-rich fraction is condensed by condenser-reboiler 68 to provide reflux for both the high and low pressure columns, the condensation being effected by indirect heat exchange with liquid oxygen collecting in the bottom of the low pressure column 66. A part of the liquid oxygen is thereby reboiled. Low pressure column 66 also produces a nitrogen vapour fraction at its top.

The first subsidiary air stream 36, having been fully cooled, is introduced into a heat exchanger 70 located within the bottom of high pressure column 64 where it is further cooled. The further cooled first subsidiary air stream 36 is reduced in pressure to that of high pressure column 64 by a Joule-Thomson valve 72 and is downstream thereof introduced into high pressure column 64 for rectification. The heat exchanger 70 cools the air by indirect heat exchange with oxygen-rich liquid in the bottom of the high pressure column 64. Some of the oxygen-rich liquid vaporises and thus boil-up is created for the high pressure column 64.

The second subsidiary air stream 32, downstream of its having been expanded by expander 38, is combined with fully cooled third subsidiary air stream 44 and is introduced into the bottom of the high pressure column 64 for rectification. The fourth subsidiary air stream 46 downstream of having been fully cooled within the fifth passageway 58 of main heat exchanger 24 is introduced into the low pressure column 66 for rectification.

The high pressure column 64 is provided with contacting elements, for instance, structured packing, trays, or random packing designated by reference numeral 74. Low pressure column 66 is provided with such contacting elements, designated by reference numeral 76. Within each column, a vapour phase becomes richer in the more volatile component, nitrogen, as it ascends and a liquid phase, as it descends, becomes more concentrated in the less volatile component, oxygen. Contacting elements 74 and 76 bring these two phases into intimate contact in order to effect the mass exchange.

Oxygen-enriched liquid is withdrawn from the high pressure column 64 as a crude oxygen stream 78. The crude oxygen stream 78 is subcooled within subcooler 80 and is reduced in pressure by a Joule-Thomson valve 82 to the operating pressure of low pressure column 66 upstream of its introduction into the low pressure column 66. The condensed nitrogen-rich vapour of high pressure column 64 is divided into two streams 84 and 86 which are used to reflux high pressure column 64 and low pressure column 66, respectively. The stream 86 is subcooled in subcooler 80, reduced in pressure to that of low pressure column 66 by a Joule-Thomson valve 87 and introduced into the top of low pressure column 66. A reflux stream 88 having a composition near that of liquid air is withdrawn from high pressure column 64 and passed through subcooler 80. This reflux stream is passed through a Joule-Thomson valve 90 to reduce its pressure upstream of its introduction into low pressure column 66. This reflux stream 88 serves the purpose of optimizing the reflux conditions within high and low pressure columns 64 and 66. Waste nitrogen composed of the nitrogen vapour produced within the low pressure column 66 is withdrawn therefrom as a waste nitrogen stream 92. The waste nitrogen stream 92 is warmed within the subcooler 80 and is introduced into the sixth passageway 60 of the main heat exchanger 24 and warmed to ambient temperature. The warmed waste nitrogen stream may be vented from the plant but, as illustrated, may be supplied to purification unit 16 for regeneration purposes upstream of its being vented.

The oxygen product is provided by removing a liquid oxygen stream 94 from low pressure column 66 and pumping it by a pump 96 to a delivery pressure. The pump 96 communicates with the second passageway 28 of the main heat exchanger. The liquid oxygen stream vaporizes therein and is warmed to ambient temperature and may be taken as a prescribed gaseous oxygen product.

EXAMPLE

In the calculated example, presented in the table below, 1067.7 Nm^3/min of oxygen product (of about 95% purity) is produced at a pressure of approximately 46.2 bar(a). The details of operation of high and low pressure columns are essentially conventional and as such are not set forth herein. It is to be noted though, that pumped oxygen stream 94 enters main heat exchanger 24 at a pressure of about 42.8 bar(a) and a temperature of about -177.8°C after having been pumped from a pressure of 1.43 bar and a temperature of about -180.1°C. Waste nitrogen stream 92 at a flow rate of about 3772.5 Nm^3/min enters main heat exchanger at a temperature of -175.6°C.

Stream	**Flow** (Nm^3/min)	**Temp** (°C)	**Pressure** (bara)
Compressed air stream 13 after air pre-purification unit 16	4840.3	29.4	5.52

(continued)

Stream	Flow (Nm^3/min)	Temp (°C)	Pressure (bara)
Further compressed air stream 20 after second after-cooler 22	1905.9	29.4	44.83
First subsidiary air stream before heat pump compressor 34	1380.1	-123.3	44.6
Still further compressed stream 36 after introduction into main heat exchanger 24 and just prior to entering second section 26b of first passageway 26	1380.1	-96.6	74.6
Still further compressed stream 36 after full cooling in main heat exchanger 24	1380.1	-173.3	74.5
Second subsidiary stream 32 prior to expander 38	525.8	-94.3	44.8
Second subsidiary stream 32 after expansion in expander 38	525.8	-172.8	5.38
Third subsidiary air stream 44 after cooling within main heat exchanger 24	2540.1	-173.3	5.45
Fourth subsidiary air stream 46 after refrigeration booster compressor 50 and after-cooler 52	394.3	29.4	8.78
Fourth subsidiary air stream 46 after partial cooling within main heat exchanger 24	394.3	-95.6	8.64
Fourth subsidiary air stream 46 after refrigeration turboexpander 56	394.3	-156.7	1.50
Fourth subsidiary air stream 46 after passage through main heat exchanger 24	394.3	-173.3	1.45

In order to effect the same oxygen production by a comparable known method and apparatus, it has been calculated that a compressed air stream functioning as further compressed air stream 20 to vaporize the liquid oxygen would have to be compressed to a pressure of about 74.48 bar(a) and a flow of 1761.3 Nm^3/min.

Although the process and apparatus of the described example of the present invention use a double column, it is to be understood that a single column may be used instead.

Furthermore, although first and second subsidiary streams 30 and 32 are removed from separate points in main heat exchanger 24, it is possible to remove them at the same temperature. Moreover, although second subsidiary stream 32 is formed from part of further compressed air stream 20, it could also be formed from another air stream being cooled within main heat exchanger 24 or in case of an application other than air separation, some other process stream containing the gaseous mixture and being cooled within the main heat exchanger.

With reference again to Figure 3 of the drawings, it is to be understood that the pinch point C' occurs at approximately the temperature at which the liquid oxygen stream starts to boil in the main heat exchanger. It is further to be understood that if the oxygen is required at its critical pressure (5043 kPa) or above there is no discrete change of phase of the oxygen in the main heat exchanger. References herein to vaporisation of liquid oxygen are thus intended to include within their scope the warming of a stream of oxygen at a supercritical pressure from below to above the critical temperature.

Claims

1. A process for separating air including the steps of forming a first lower pressure stream (44) and a second higher pressure stream (20) of compressed air;

   cooling the first air stream (44) by heat exchange in a main heat exchanger (24) to a temperature suitable for its separation by rectification;

   rectifying the first air stream (44) to form nitrogen and liquid oxygen fractions;

pressurising a stream of the liquid oxygen fraction;

heat exchanging a stream of the nitrogen fraction and the pressurised liquid oxygen stream with the first air stream (44) so as to effect the cooling of the first air stream (44) and vaporisation of the pressurised liquid oxygen stream;

cooling the second air stream (20) by heat exchange in the main heat exchanger (24) with the nitrogen and pressurised liquid oxygen streams to a temperature intermediate the cold end and warm end temperatures of the main heat exchanger (24) characterised by introducing at least part of the cooled second air stream (20) at said intermediate temperature into a compressor (34);

compressing said part of the cooled second air stream (20) in the compressor (34); and

further cooling the compressed part of the cooled second air stream (20) in the main heat exchanger (24) and rectifying the further cooled second air stream (20) with the first air stream (44), and in that the said intermediate temperature to which the second air stream (20) is cooled is in the vicinity of a theoretical pinch point temperature determined for the main heat exchanger (24).

2. A process according to claim 1, wherein the first and second compressed air streams (44 and 20) are formed by compressing a flow of air, removing heat of compression from the compressed air, purifying the compressed air, further compressing a portion of the purified air, and removing heat of compression from the further compressed air.

3. A process according to claim 1 or claim 2, wherein a part of the second compressor air stream (20) is taken from a region of the main heat exchanger (24) upstream of said vicinity and is expanded with the performance of expansion work, and at least part of the expansion work is applied to the compressor (34).

4. A process according to any one of the preceding claims, wherein:

the rectification is performed in a double rectification column (62) having high and low pressure columns (64, 66) connected to one another in a heat transfer relationship such that liquid oxygen and nitrogen vapour are produced in the low pressure column (66), oxygen enriched liquid and nitrogen rich vapour are produced in the high pressure column (64), and liquid oxygen so formed vaporizes in indirect heat exchange with the nitrogen rich vapour, thereby condensing said nitrogen rich vapour;

a stream of the oxygen-rich liquid and a stream of the condensed nitrogen-rich vapour are respectively withdrawn from the high pressure column (64), subcooled, and reduced in pressure to low pressure column (66) pressure;

the oxygen-rich liquid stream is introduced into the low pressure column (66) for rectification and the nitrogen rich liquid stream is introduced into the low pressure column (66) as reflux;

the said stream of the liquid oxygen fraction is withdrawn from the low pressure column; and

a nitrogen vapour stream is withdrawn from the low pressure column, is partially warmed through heat exchange with the oxygen rich liquid stream and the nitrogen rich condensate stream thereby to sub-cool the oxygen-rich liquid stream and the nitrogen rich condensate stream, and is introduced into the main heat exchanger and is warmed therein.

5. An apparatus for producing an oxygen product at a delivery pressure from air, said apparatus comprising:

a main compressor (12) for compressing the air;

a first after-cooler (14) communicating with the main compressor (12) for removing heat of compression from the air;

air pre-purification means (16) communicating with the first after-cooler (14) for purifying the air;

a high pressure air compressor (18) connected to the air pre-purification means (16) for further compressing

at least a portion of the air to form a further compressed air stream;

a second after-cooler (22) communicating with the high pressure air compressor (18) for removing heat of compression from the further compressed air stream;

a main heat exchanger (24) having a first passageway (26) including first and second sections (26a, 26b), the first section (26a) in communication with said second after-cooler (22) such that said compressed air stream flows into said first section (26a) of the first passageway (26), a second passageway (28), means for discharging first and second subsidiary air streams (32,30) composed of the compressed air stream from the first section (26a) of the first passageway (26) so that at least the first subsidiary air stream (32) upon discharge has a temperature in the vicinity of a theoretical pinch point temperature determined for the main heat exchanger (24), and an inlet situated at a location of the main heat exchanger having a warmer temperature than the theoretical pinch point temperature for receiving the first subsidiary air stream (30) after compression thereof, the second section (26b) of the first passageway (26) communicating with the inlet and positioned such that the first subsidiary air stream fully cools;

a heat pump compressor (34) for compressing the first subsidiary air stream intermediate the said discharge means of the main heat exchanger (24) and the said inlet thereto;

expansion means (38) for expanding the second subsidiary air stream (32) with the performance of expansion work;

the expansion means (38) coupled to the heat pump compressor (34) such that at least part of the expansion work drives the heat pump compressor (34);

air rectification (62) means connected to the expansion means (38) and the second section (26b) of the first passageway (26) of the main heat exchanger (24) for rectifying the air and thereby producing liquid oxygen;

a pump (96) connected to the air rectification means (62) for pumping the liquid oxygen and thereby forming a pumped liquid oxygen stream;

the pump connected to the second passageway (28) of the main heat exchanger (24) such that the pumped liquid oxygen stream flows in a counter-current direction to the compressed air stream within the first passageway and is thereby vaporized to produce the gaseous oxygen product; and

refrigeration means (38,56) for supplying refrigeration to the apparatus such that energy balance thereof is maintained.

Patentansprüche

1. Prozeß zum Trennen von Luft, der die Schritte umfaßt, daß ein erster Strom (44) mit niedrigerem Druck und ein zweiter Strom (20) mit höherem Druck an komprimierter Luft gebildet wird;

der erste Luftstrom (44) durch Wärmeaustausch in einem Hauptwärmetauscher (24) auf eine Temperatur gekühlt wird, die für seine Trennung durch Rektifikation geeignet ist;

der erste Luftstrom (44) rektifiziert wird, um Stickstoff- und Flüssigsauerstoffraktionen zu bilden;

ein Strom der Flüssigsauerstoffraktion unter Druck gesetzt wird;

ein Strom der Stickstoffraktion und der unter Druck gesetzte Flüssigsauerstoffstrom mit dem ersten Luftstrom (44) einem Wärmeaustausch unterzogen wird, um so die Kühlung des ersten Luftstromes (44) und eine Verdampfung des unter Druck gesetzten Flüssigsauerstoffstromes zu bewirken;

der zweite Luftstrom (20) durch Wärmeaustausch in dem Hauptwärmetauscher (24) mit dem Stickstoff und unter Druck gesetzten Flüssigsauerstoffströmen auf eine Temperatur gekühlt wird, die zwischen den Temperaturen des kalten und warmen Endes des Hauptwärmetauschers (24) liegt, dadurch gekennzeichnet, daß

zumindest ein Teil des gekühlten zweiten Luftstromes (20) bei der Zwischentemperatur in einen Kompressor (34) eingeführt wird;

der Teil des gekühlten zweiten Luftstromes (20) in dem Kompressor (34) komprimiert wird; und

der komprimierte Teil des gekühlten zweiten Luftstromes (20) in dem Hauptwärmetauscher (24) weiter gekühlt wird, und der weiter gekühlte zweite Luftstrom (20) mit dem ersten Luftstrom (44) rektifiziert wird, und daß die Zwischentemperatur, auf die der zweite Luftstrom (20) gekühlt wird, in der Nähe einer theoretischen Einschnürpunkttemperatur liegt, die für den Hauptwärmetauscher (24) bestimmt wird.

2. Prozeß nach Anspruch 1, wobei die ersten und zweiten komprimierten Luftströme (44 und 20) dadurch gebildet werden, daß eine Luftströmung komprimiert wird, Komprimierungswärme von der komprimierten Luft entfernt wird, die komprimierte Luft gereinigt wird, ein Anteil der gereinigten Luft weiter komprimiert wird und Komprimierungswärme von der weiter komprimierten Luft entfernt wird.

3. Prozeß nach Anspruch 1 oder Anspruch 2, wobei ein Teil des zweiten Kompressorluftstromes (20) von einem Bereich des Hauptwärmetauschers (24) oberstromig der Nähe entnommen und unter Ausführung von Expansionsarbeit expandiert wird, und zumindest ein Teil der Expansionsarbeit an den Kompressor (34) angewendet wird.

4. Prozeß nach einem der vorhergehenden Ansprüche, wobei:

die Rektifikation in einer Doppelrektifikationskolonne (62) mit Hoch- und Niederdruckkolonnen (64, 66) ausgeführt wird, die miteinander derart in einer Wärmeübertragungsbeziehung verbunden sind, daß flüssiger Sauerstoff und Stickstoffdampf in der Niederdruckkolonne (66) erzeugt wird, sauerstoffangereicherte Flüssigkeit und stickstoffreicher Dampf in der Hochdruckkolonne (64) erzeugt werden und so gebildeter flüssiger Sauerstoff in indirektem Wärmeaustausch mit dem stickstoffreichen Dampf verdampft, wodurch der stickstoffreiche Dampf kondensiert wird;

ein Strom der sauerstoffreichen Flüssigkeit und ein Strom des kondensierten stickstoffreichen Dampfes jeweils von der Hochdruckkolonne (64) abgezogen, unterkühlt und auf den Druck der Niederdruckkolonne (66) druckgemindert werden;

der sauerstoffreiche Flüssigkeitsstrom in die Niederdruckkolonne (66) zur Rektifikation eingeführt wird, und der stickstoffreiche Flüssigkeitsstrom in die Niederdruckkolonne (66) als Rückfluß eingeführt wird;

der Strom der flüssigen Sauerstofffraktion von der Niederdruckkolonne abgezogen wird; und

ein Stickstoffdampfstrom von der Niederdruckkolonne abgezogen wird, durch Wärmeaustausch mit dem sauerstoffreichen Flüssigkeitsstrom und dem stickstoffreichen Kondensatstrom teilweise erwärmt wird, wodurch der sauerstoffreiche Flüssigkeitsstrom und der stickstoffreiche Kondensatstrom unterkühlt wird, und in den Hauptwärmetauscher eingeführt und darin erwärmt wird.

5. Vorrichtung zum Erzeugen eines Sauerstoffproduktes bei einem Lieferdruck von Luft, wobei die Vorrichtung umfaßt:

einen Hauptkompressor (12) zum Komprimieren der Luft;

einen ersten Nachkühler (14), der mit dem Hauptkompressor (12) in Verbindung steht, um Komprimierungswärme von der Luft zu entfernen;

ein Luftvorreinigungsmittel (16), das mit dem ersten Nachkühler (14) zum Reinigen der Luft in Verbindung steht;

einen Hochdruckluftkompressor (18), der mit dem Luftvorreinigungsmittel (16) verbunden ist, um zumindest einen Anteil der Luft weiter zu komprimieren und einen weiter komprimierten Luftstrom zu bilden;

einen zweiten Nachkühler (22), der mit dem Hochdruckluftkompressor (18) in Verbindung steht, um Komprimierungswärme von dem weiter komprimierten Luftstrom zu entfernen;

einen Hauptwärmetauscher (24) mit einem ersten Durchgang (26), der erste und zweite Teilabschnitte (26a, 26b) enthält, wobei der erste Teilabschnitt (26a) mit dem zweiten Nachkühler (22) derart in Verbindung steht, daß der komprimierte Luftstrom in den ersten Teilabschnitt (26a) des ersten Durchganges (26) strömt, mit einem zweiten Durchgang (28), mit einem Mittel, um erste und zweite Nebenluftströme (32, 30) auszutragen, die aus dem komprimierten Luftstrom von dem ersten Teilabschnitt (26a) des ersten Durchganges (26) bestehen, so daß zumindest der erste Nebenluftstrom (32) nach einem Austrag eine Temperatur in der Nähe einer theoretischen Einschnürpunkttemperatur besitzt, die für den Hauptwärmetauscher (24) bestimmt wird, und mit einem Einlaß, der an einem Ort des Hauptwärmetauschers angeordnet ist, der eine wärmere Temperatur aufweist, als die theoretische Einschnürpunkttemperatur, um den ersten Nebenluftstrom (30) nach seiner Komprimierung zu empfangen, wobei der zweite Teilabschnitt (26b) des ersten Durchganges (26) mit dem Einlaß in Verbindung steht und derart positioniert ist, daß der erste Nebenluftstrom vollständig gekühlt wird;

einen Wärmepumpenkompressor (34) zum Komprimieren des ersten Nebenluftstromes zwischen dem Austragsmittel des Hauptwärmetauschers (24) und dem Einlaß daran;

ein Expansionsmittel (38) zum Expandieren des zweiten Nebenluftstromes (32) unter Ausführung von Expansionsarbeit;

wobei das Expansionsmittel (38) derart an den Wärmepumpenkompressor (34) gekoppelt ist, daß zumindest ein Teil der Expansionsarbeit den Wärmepumpenkompressor (34) antreibt;

ein Luftrektifikationsmittel (62), das mit dem Expansionsmittel (38) und dem zweiten Teilabschnitt (26b) des ersten Durchganges (26) des Hauptwärmetauschers (24) verbunden ist, um die Luft zu rektifizieren und dadurch flüssigen Sauerstoff zu erzeugen;

eine Pumpe (96), die mit dem Luftrektifikationsmittel (62) verbunden ist, um den flüssigen Sauerstoff zu pumpen und dadurch einen gepumpten Flüssigsauerstoffstrom zu bilden;

wobei die Pumpe mit dem zweiten Durchgang (28) des Hauptwärmetauschers (24) derart verbunden ist, daß der gepumpte Flüssigsauerstoffstrom in einer Gegenstromrichtung zu dem komprimierten Luftstrom innerhalb des ersten Durchganges strömt und dadurch verdampft wird, um das gasförmige Sauerstoffprodukt zu erzeugen; und

ein Kühlmittel (38, 56) zum Liefern einer Kühlung an die Vorrichtung, so daß deren Energiegleichgewicht beibehalten wird.

Revendications

1. Procédé de séparation de l'air comprenant les étapes de : formation d'un premier flux (44) d'air comprimé à pression inférieure et d'un second flux (20) d'air comprimé à pression supérieure ;

   refroidissement du premier flux d'air (44) par échange thermique dans un échangeur de chaleur principal (24) à une température appropriée pour sa séparation par rectification ;
   rectification du premier flux d'air (44) pour former des fractions azote et oxygène liquide ;
   mise sous pression d'un flux de la fraction oxygène liquide ;
   mise en échange thermique d'un flux de la fraction azote et du flux d'oxygène liquide sous pression avec le premier flux d'air (44) afin de réaliser le refroidissement du premier flux d'air (44) et la vaporisation du flux d'oxygène liquide sous pression ;
   refroidissement du second flux d'air (20) par échange thermique dans l'échangeur de chaleur principal (24) avec les flux d'azote et d'oxygène liquide sous pression, jusqu'à une température intermédiaire des températures du bout froid et du bout chaud de l'échangeur de chaleur principal (24), ***caractérisé par*** l'introduction d'au moins une partie du second flux d'air (20) refroidi à ladite température intermédiaire dans un compresseur (34) ;
   la compression de ladite partie du second flux d'air (20) refroidi dans le compresseur (34) ; et
   la poursuite du refroidissement de la partie comprimée du second flux d'air (20) refroidi dans l'échangeur de chaleur principal (24) et la rectification du second flux d'air (20) plus amplement refroidi avec le premier flux d'air (44), et ***en ce que*** ladite température intermédiaire à laquelle est refroidi le second flux d'air (20) est au

voisinage d'une température théorique du point de resserrement ("pinch point") déterminé pour l'échangeur de chaleur principal (24).

2. Procédé selon la Revendication 1, dans lequel les premier et second flux d'air comprimés (44 et 20) sont formés par compression d'un courant d'air, élimination de la chaleur de compression de l'air comprimé, épuration de l'air comprimé, poursuite de la compression d'une portion de l'air épuré, et élimination de la chaleur de compression de l'air plus amplement comprimé.

3. Procédé selon la Revendication 1 ou la Revendication 2, dans lequel une partie du second flux d'air comprimé (20) est prise dans une région de l'échangeur de chaleur principal (24) en amont dudit voisinage et est détendue avec accomplissement d'un travail de détente, et au moins une partie du travail de détente est appliqué au compresseur (34).

4. Procédé selon l'une quelconque des Revendications précédentes, dans lequel :

   la rectification est effectuée dans une double colonne de rectification (62) ayant des colonnes haute et basse pression (64, 66) reliées l'une à l'autre en relation d'échange thermique de telle façon que de l'oxygène liquide et de la vapeur d'azote soient produits dans la colonne basse pression (66), du liquide enrichi en oxygène et de la vapeur riche en azote soient produits dans la colonne haute pression (64), et que l'oxygène liquide ainsi formé se vaporise en échange thermique indirect avec la vapeur riche en azote, faisant ainsi se condenser ladite vapeur riche en azote ;
   un flux du liquide riche en oxygène et un flux de vapeur riche en azote et condensée sont respectivement soutirés de la colonne haute pression (64), sous-refroidis, et leur pression est réduite à la pression de la colonne basse pression (66) ;
   le flux de liquide riche en oxygène est introduit dans la colonne basse pression (66) pour rectification et le flux de liquide riche en azote est introduit dans la colonne basse pression (66) sous forme de reflux ;
   ledit flux de la fraction oxygène liquide est soutiré de la colonne basse pression ; et
   un flux de vapeur d'azote est soutiré de la colonne basse pression, est partiellement réchauffé par échange thermique avec le flux de liquide riche en oxygène et le flux de condensat riche en azote, sous-refroidissant ainsi le flux de liquide riche en oxygène et le flux de condensat riche en azote, et est introduit dans l'échangeur de chaleur principal où il est réchauffé.

5. Dispositif pour la production, sous une pression de refoulement, d'oxygène de production à partir d'air, ledit dispositif comprenant :

   un compresseur principal (12) pour comprimer l'air ;
   un premier post-refroidisseur (14) communiquant avec le compresseur principal (12) pour éliminer la chaleur de la compression de l'air ;
   des moyens de pré-épuration (16) de l'air communiquant avec le premier post-refroidisseur (14) pour épurer l'air ;
   un compresseur d'air haute pression (18) relié aux moyens de pré-épuration (16) de l'air pour poursuivre la compression d'au moins une partie de l'air pour former un flux d'air plus amplement comprimé ;
   un second post-refroidisseur (22) communiquant avec le compresseur (18) d'air haute pression pour éliminer la chaleur de compression du flux d'air plus amplement comprimé ;
   un échangeur de chaleur principal (24) ayant un premier passage (26) comprenant des première et seconde sections (26a, 26b), la première section (26a) étant en communication avec ledit second post-refroidisseur (22) de telle façon que ledit flux d'air comprimé s'écoule dans ladite première section (26a) du premier passage (26), un second passage (28), des moyens pour décharger des premier et second flux d'air auxiliaires (32, 30) composés du flux d'air comprimé de la première section (26a) du premier passage (26) afin qu'au moins le premier flux d'air auxiliaire (32) lors de sa décharge ait une température au voisinage d'une température théorique du point de resserrement déterminée pour l'échangeur de chaleur principal (24), et une entrée située en un emplacement de l'échangeur de chaleur principal ayant une température supérieure à la température théorique du point de resserrement et destinée à recevoir le premier flux d'air auxiliaire (30) après compression de celui-ci, la seconde section (26b) du premier passage (26) communiquant avec l'entrée et étant positionnée de telle manière que le premier flux d'air auxiliaire se refroidisse totalement ;
   un compresseur (34) de pompe à chaleur pour comprimer le premier flux d'air auxiliaire, placé entre lesdits moyens de décharge de l'échangeur de chaleur principal (24) et ladite entrée de celui-ci ;
   des moyens de détente (38) pour détendre le second flux d'air auxiliaire (32) avec accomplissement d'un

travail de détente ;
les moyens de détente (38) étant couplés au compresseur (34) de pompe à chaleur de telle façon qu'au moins une partie du travail de détente entraîne le compresseur (34) de pompe à chaleur ;
des moyens (62) de rectification de l'air raccordés aux moyens de détente (38) et à la seconde section (26b) du premier passage (26) de l'échangeur de chaleur principal (24) pour rectifier l'air et ainsi produire de l'oxygène liquide ;
une pompe (96) raccordée aux moyens de rectification de l'air (62), destinée à pomper l'oxygène liquide et à former ainsi un flux d'oxygène liquide pompé ;
la pompe étant raccordée au second passage (28) de l'échangeur de chaleur principal (24) de telle façon que le flux d'oxygène liquide pompé s'écoule à contre-courant du flux d'air comprimé à l'intérieur du premier passage et soit ainsi vaporisé pour produire l'oxygène gazeux de production ; et
des moyens de réfrigération (38, 56) pour assurer la réfrigération du dispositif de telle façon que le bilan énergétique de celui-ci soit maintenu.

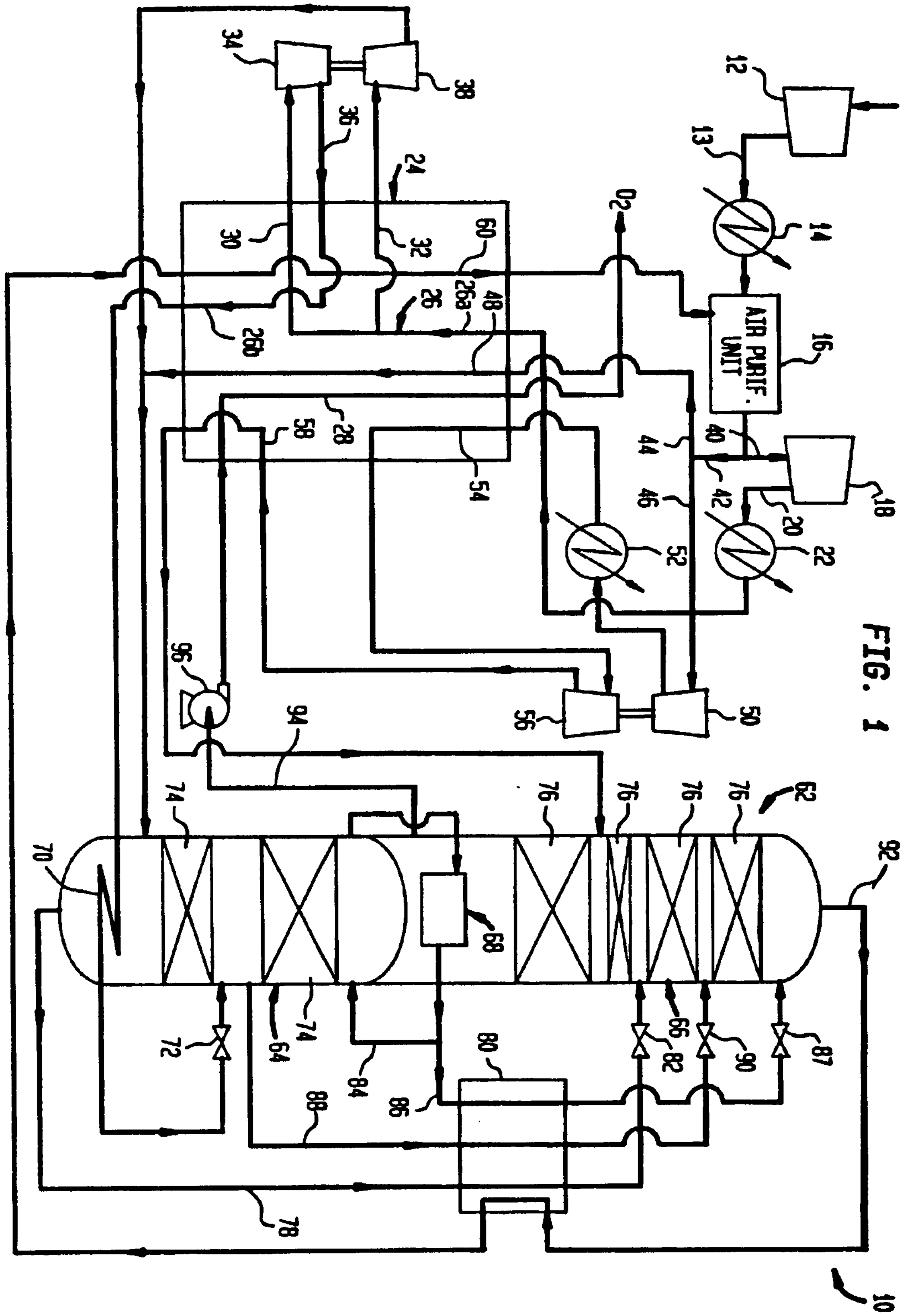
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FIG. 1

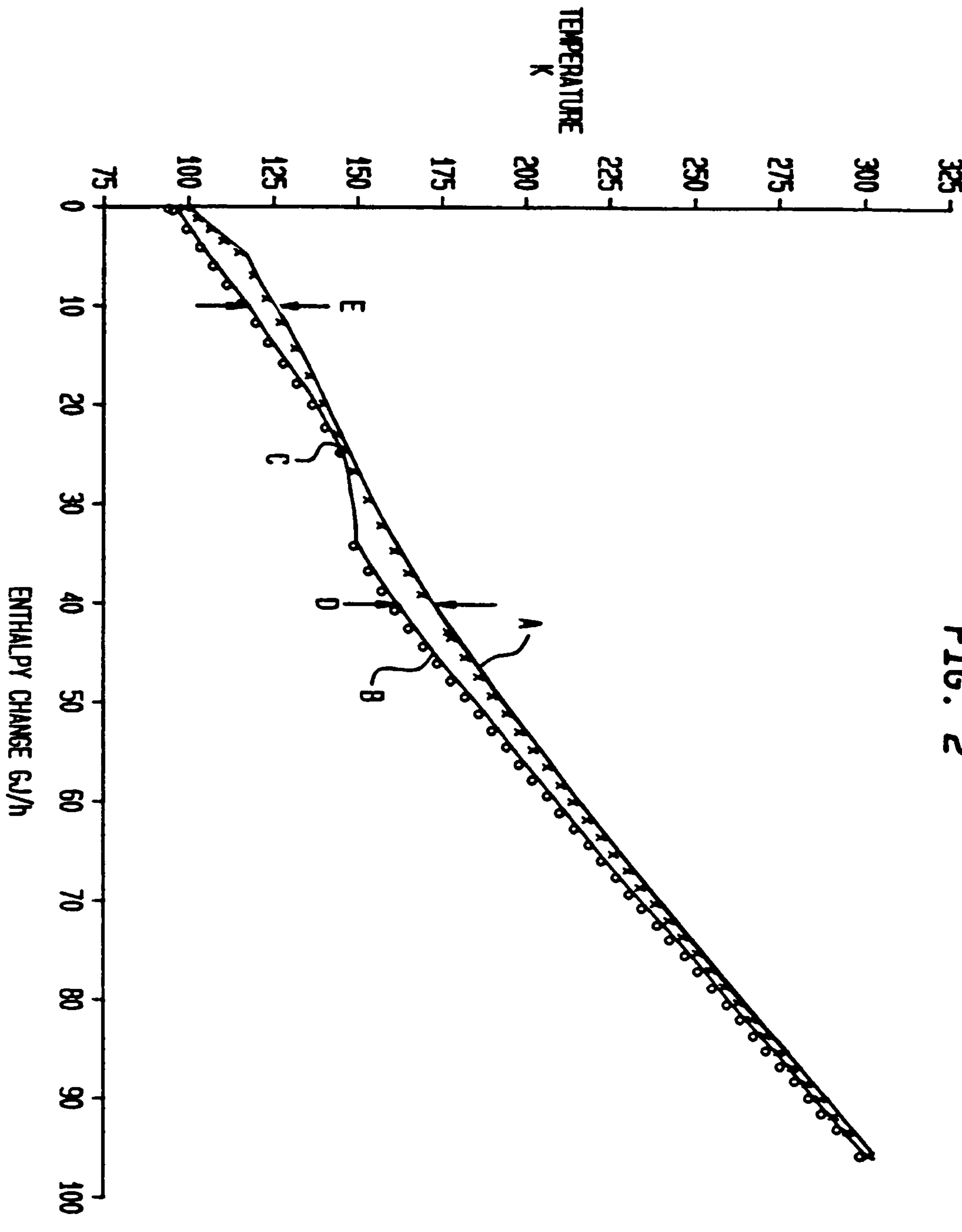
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FIG. 2

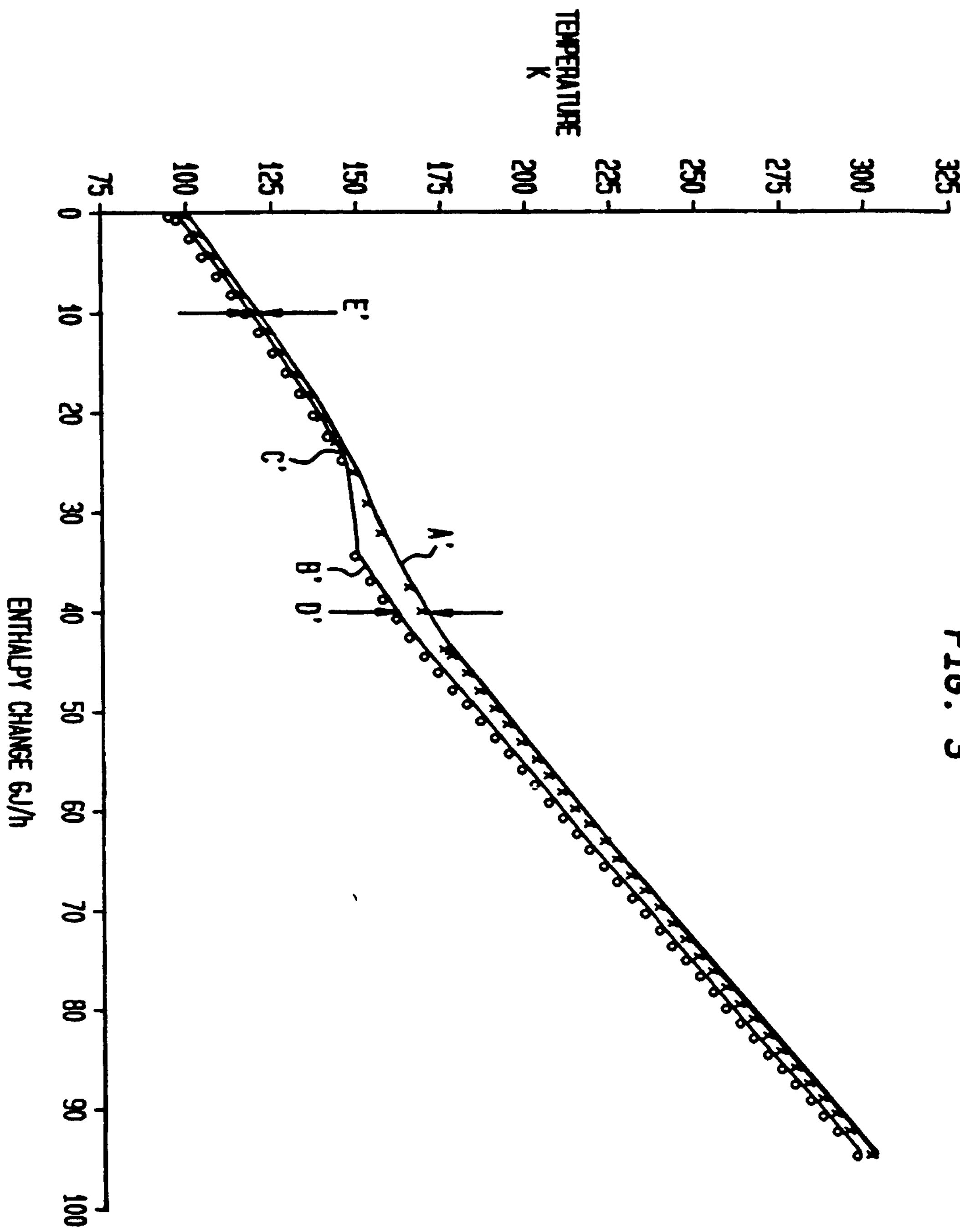
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FIG. 3